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Technical Report S-272

HYDROGEN FLUORIDE CHEMICAL LASER- A DEMONSTRATION OF PURE CHEMICAL PUMPING IIL CHEMICAL PUMPING IN A LAMINAR DIFFUSIVE-MIXING LASER SYSTEM

by

Joseph F. Spinnler

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November 1970

U. S. ARMY MISSILE COMMAND REDSTONE ARSENAL, ALABAMA 35809

Contract DAAH01-70-C-0146, P001

ROHM AND HAAS COMPANY

REDSTONE RESEARCH LABORATORIES HUNTSVILLE, ALABAMA 35807

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tу

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FOREWORD

The work in this report was conducted under Contract DAAH01-70-C-0146, P001 for research on high-energy chemical lasers under the technical cognizance of APL&C, Research and Engineering Directorate, U. S. Army Missile Command, Redstone Arsenal, Alabama. The specific objective of the laser contracts at these Laboratories has been to demonstrate continuous laser action by stimulated emission of hydrogen fluoride pumped solely by the energy released by the homogeneous chemical reaction between hydrogen and fluorine.

Neither the suitability of HF as an emitter nor the efficacy of H_2 - F_2 pumping had been demonstrated at the time work began. Since then, single-pulse laser action of H_2 - F_2 has been demonstrated (within the first year's contract), and stimulated emission of HF excited by external means has been reported by other investigators.

Successful chemical pumping by hydrogen and fluorine in a continuous-flow system to excite stimulated emission of carbon dioxide has been reported in the literature. More recently, pumping of CO₂ via HF and DF, and the pumping of HF using the energy of chemical reaction alone has been reported, with the latter investigations having been accomplished concurrent with successful results in these Laboratories.

This report is the fourth of a series detailing the laser work in the Redstone Laboratories. The first report (S-139, July 1967) gave the results of gain calculations to determine the energy distribution theoretically achievable in HCl and HF as emitters. The second report (S-163, May 1968) described the design and construction of the apparatus, as well as the experimental results obtained during the first year of investigation, culminating in the successful demonstration of pure chemically pumped laser action with hydrogen and fluorine in a single-pulse system. The third report dealt with progress toward a continuous-flow system, including construction of an improved fast-mixing injector to supersede the impinging-jet system used earlier, and various methods of inducing population inversion through introduction of a third species such as NO or fluorine atoms.

This report constitutes the final report on Contract DAAH01-70-C-0146, P001 and, together with the preceding reports under Contracts DAAH-01-67-C-1475 and DAAH01-69-C-0206, covers all the laser work in these Laboratories.

The author wishes to acknowledge the help and advice of our consultants, Professors S. H. Bauer of Cornell University and C. Bradley Moore of the University of California (Berkeley), and the assistance of Professor T. A. Cool of Cornell University for his design of the laminar diffusive burner.

We also acknowledge the assistance of the personnel of the Rohm and Haas Redstone Research Laboratories Engineering Design Group and the excellent job of fabrication of the required equipment by the personnel of the Mechanical Instrument Shop. The assistance of personnel of the Instrument Development Group in detector instrumentation and design and fabrication of the safety system is greatly appreciated. The contributions of technical assistants Messrs. J. W. Clark, W. F. Hooper, and W. M. Davis are also gratefully acknowledge.

Captain William Glass of the Physical Sciences Laboratory, R&E Directorate, U. S. Army Missile Command also assisted in the work covered in this report. Captain Glass's faith in the project, his efforts in obtaining funding, and assistance in the experiments contributed infinitely to the measure of success that was obtained.

ABSTRACT

This report describes results of continuing experiments in a laminar-diffusive mixing laser system. Conclusive evidence for CW coherent laser action of hydrogen fluoride is offered, with pumping energy supplied solely by the energy of chemical reaction. Flow conditions of H_2 and F_2 and other fuels and reactant gases are also presented.

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Section 1. INTRODUCTION

The objective of the laser research at the Redston-Research Laboratories of Rohm and Haas Company was the demonstration of a continuous chemically pumped laser; i.e., the chemical energy of molecular reactions generates population inversion in a reactant species. Most lasers require an external pumping system such as flash lamps, electrical discharge, or arc heating of reactant species. This report describes experiments conducted in these Laboratories using a laminar diffusive-mixing laser system in which continuous-wave (CW) and coherent energy output was observed. Moreover, pumping energy was available only from gaseous reactions (F_2 + NO and F_3), a pure chemical laser.

Earlier work in these Laboratories consisted of theoretical analysis of chemical laser systems (1)¹ and design, construction, and experimentation on two types of laser systems — a single-pulse laser system and a turbulent-flow mixing system (2). During the period reported therein, emission characteristic of laser radiation was observed in the single-pulse laser system. Radiation of a similar character was observed in the turbulent-flow system; however, its laser characteristics could not be verified as was done in the case of the single-pulse laser system in ensuing experiments on these systems (3, 4). Rationale leading to design and construction of the laminar diffusive-mixing laser system and initial experimentation are also detailed in Reference 4.

Work reported herein is a continuation of experimentation with the laminar diffusive-mixing laser system. Various flows, mixture ratios of diluents and reactants, and mixing locations in the system under a variety of cavity pressures were investigated. The F atom forming reaction

$$F_2 + NO \rightarrow NOF + F$$
 (1)

was utilized along with various hydrogenated and deuterated reactant fuels. CO_2 was also injected without success. Use of SF_6 was made in order that the system be cryogenically purified.

¹Numbers in parentheses refer to references at the end of the report.

CW coherent radiation was observed in the case in which precooled fluorine was used. A hydrogen - nitric oxide fuel and sulfur hexafluoride diluent were used in these successful experiments. Low output power prevented characterization of the radiation; however, coherence was verified by determining of the laser cavity.

Section II. EXPERIMENTAL

1. Apparatus

The laminar diffusive-mixing laser system, which includes laser cavity, optical cavity, detector-optical system, gas-metering system, safety system and exhaust system, has been described in detail in References 2 and 3. This system, so described, with minor variations in the plumbing for accommodation of gases and gas mixing locations for various experiments and modifications of cavity optics (variation in mirror reflective surface and focal length), was utilized for the work reported here. The laminar diffusive laser, itself, is shown in Figure 1A. A view of the total system, cavity, optics, reflectors, etc., is shown in Figure 1B.

The optical and detector systems normally utilized are shown in Figure 2. In the experiments in which coherent radiation was detected, the laser cavity mirror (M_1 of Figure 2, the concave mirror) was of 500-mm focal length. This change was made in order that the cavity mode volume might be increased somewhat.

Only the AuGe detector sub-system was useful in the experiments because output intensity was minimal.

A schematic of the flow system is shown in Figure 3. Modifications made involved relocation of various mixing locations for nitric oxide and diluent.

For the experiments in which F_2 and NO were premixed before admission, this mixing was done in the F_2 manifold of the laser cavity (Figure 4). In the experiments in which the F_2 was cooled, F_2 was allowed to flow first through the rotameter, then through a copper coil immersed in a dry ice trichloroethylene bath, which was adjacent to the laser cavity, and then into the F_2 manifold.

2. Experimental Results

The data from experiments for the period covered by this report have been reduced and the results along with comments and observations tabulated in Table I. Flow rates for the experiments are given in cc/sec at STP for the various gases utilized in the experiments. Where sufficient data were lacking, flows and pressures have been estimated and indicated by (). A (+) or (-) indicates that flow was

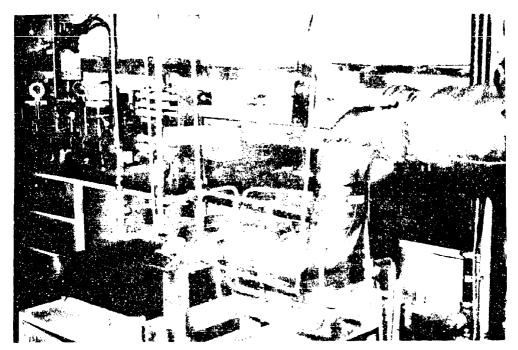


FIGURE 1A. ANGLE

OF BURNER SYSTEM

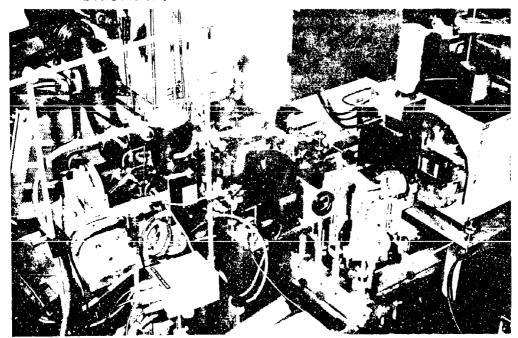


FIGURE III VO

CR AND OPTICS

FIGURE 1.

THE LAMINAR DEFEUSIVE-MIXING LASER SYSTEM

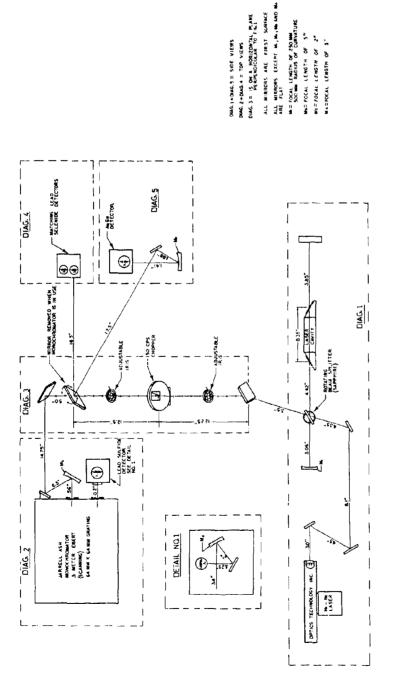


FIGURE 2. SCHEMATIC OF THE OPTICAL AND DETECTOR SYSTEMS OF THE LAMINAR DIFFUSIVE-MIXING LASER SYSTEM

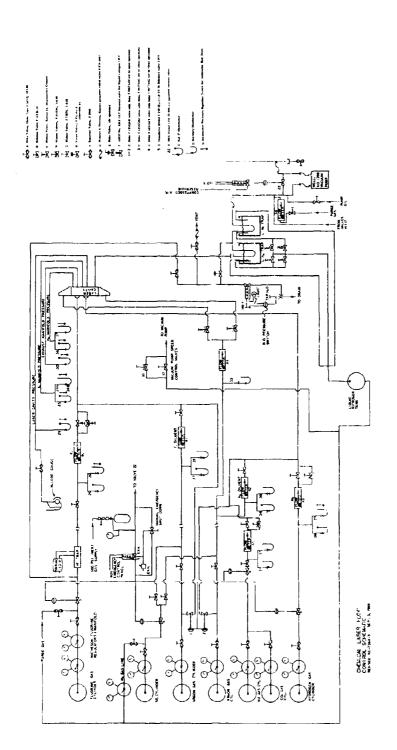
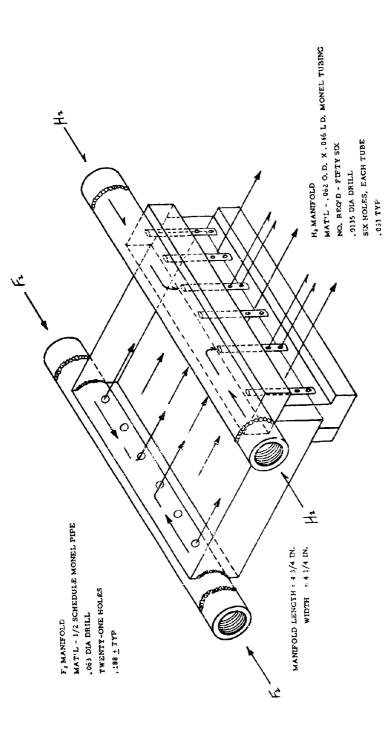


FIGURE 3. FLOW SYSTEM FOR THE LAMINAR DIFFUSIVE-MIXING LASER



FLUID MIXING TECHNIQUE FOR THE HF CHEMICAL LASER

FIGURE 4. SCHEMATIC OF THE FLUID MIXING TECHNIQUE FOR THE HF LAMINAR DIFFUSIVE-MIXING LASER

金色素を「こう」(1971年)を発表を受ける。 単独を発生を対象の関係を対して、発展されるとなっても、これではない。

Table I. — Conditions and Observations of the Laminar Influsive-Mining Lawer Experiments

Cavity Flow Area = 1,008 cm x 10,0857 cm = 10,0512 cm², Flow Velocity = Total Flow (%),615 (cavity pressure) = 65 continueds

!	Esperiment No. and Variation	1,	Os.di 7.4 Ar	Inter	SF.	11,	11,		NII,		L Dilugi		Window	Adultives	Total	Cavity	1 los Velocity	l	16.15.
27 Jan	Variation	1.,	Ar	N,	SF.	1 "	1 12	j Lille	I MII,	_ Z NC	1 Diluct								
						L	i_		i_ I	Αr	N ₁	SF,	Purge	180	Flow	(torr)	(time sec at 5TP)	\$ HE	
nat es	n	Ŧ	l			1						 -		1	1	. 575			Initial conditions
29 Jan		1			155.0	40.0						150, 9,	.4	5,0	155.7	2,1	11001	ĺ	SF4, H2, 140 finws on
39 Jan	c	13,0			155.0	40,0				j		159,0	. "	5,0	191, 9	5, 9	5573	14, 8	Fy flow on Cleange recontion in cavity
nat e.		1		1	1					1				l			}		Whitelity interpulse to increwed in pitch
1	12A					ŀ				1				ĺ		020			Initial conditions
	В			ĺ	120.0	ĺ		' I		- 1	' I	130,0		ĺ	250, 0				SF4 flow un
1	С			84, 0						ĺ	108.0				197. 0	14.5	1021	İ	Shy flow replaced by 14 flow
1	D	1 1		l		20,0		l	- 1						212.0	16, 9	1002		H ₂ , NO tlows on
1	E	14.0		84.0		20, 0					102.0		. (5, 0	228.3	18.1	254	16.6	Fy flow on Crange eagletion in revity
	F	19.0		H4. 0		20.0				- 1	100.4		. ,	3, 7	227. 9	-117.91	254	16.7	NO flow der reased. Seme visible radiation
I								ļ											se 12E
	G	19.6		M4.0		20,0		į		- 1	160.6		. 5	2.8	226.1	-(17, 7)	966	16.8	Orange radiation around H ₂ inlet ports
-	н							- 1		ļ				h. 6	231.9	-			No change in cavity observations.
1	:								ĺ	1		1		5,0	228.3	16.1	954		We change in cavity observations.
	J	14.2													223.5	-			Decreased Fg flow. Orange radiation in cavity
	к	14.2		54.0		20.0		ĺ		ı	100.0		. 1	5.0	223.5	-(19,0)	939	12,7	Changed translation stage. Moved cavity mode
	ļ							i											volume, 4" toward Hg inlet ports. No signal observed on oscilloscope (Au-Ge detector).
ĺ	L	19, 9		[120.0		ĺ				- 1	130.0			294.3	5.1	4361	12.9	Replaced No flow with SF a flow Diffuse orange
1	M	14.0			12% 0						l	.							radiation in cavity. Some signal on oscilloscope
ļ	N I			- 1								3 to , o		1, M	293.1	- (4, 4)	4523	13.0	Diffuse orange radiation in ravity
	"		į	l	į			1	İ				1	2.2	291.5	-			Same visible radiation as 12M. Cavity mode volume relocated in center position.
	0	- 1		ı	İ	i		i			ł	1	!	44	294.2	-			No change in cavity observations
Į	ъ	19.0		-	120, 0	20.0			-	,	100,0	140,0		0.0	249, 5	-(4, 3)	5087	13.1	NO flow shut off. No visible radiation in cavity
	3	l			160. a	1		1		l		64.0	Ī	ĺ	203.3	2, 4	6405	18, 7	Decreased H ₂ diluent flow. No change in
ļ		١	ļ	ļ	ļ	ļ					ĺ		1	l				•	Cavity observations.
3 Feb	12A			1			[1		1	1	1]		. 125	1		NO mixed with F2 in F2 manifold of laver cavity system. Initial cc. ditions.
l	В	ļ		ĺ	129. 0	1	1					129, 1			25H, 3	2, 25	8681		Shaflow on.
1	· ·	1		142.6			1	1	1	l,	55.0	1	ì	ł	297.6	18. 3	1236		SF4 flow replaced by Ng flow
	Б		ĺ	1	1	20. 2	į			l'			. 4	5.0	321, 1	21.1	1157		H ₂ and NO flows on
Ì	1	20, 1.	1	i	1	20	1	- 1	ļ		1	i		7. 3	143.9	22,1	1177	13.8	
		20, 5	į	1	129. 0	20.2			1			129, 1	.7	4.0	194, н	3.0	76.RZ	13.3	F ₂ flow on.
	′	29. 3		ľ		20.1		ł			-	1,34, 3	- '		194, 8	3.0	76.87	15, 5	Replaced N ₂ flow with SF ₄ flow F ₂ manifold became hot.
		ļ	1			- 1		-						Ì		D4			
4 Feb	114	Ì		l.	10, 2	ł					1	130, 2	1	1	260, 4	. 04	Į		Initial conditions,
	R C	i	İ	205. 0	,,,,,	20, 8		1		١.	28.6	' '''	. 5	- 1	459,9	26, 0	1117		SF ₆ flow on.
	ł	21,7	- 1	2114. 0	l	20.0		1	- 1	- 1	28,6			- 1	481,6	78.0	1 4116		SF ₆ flow replaced by N ₂ Ω· w
	"		ľ							l'			. ,	***	****		1,116	в, ч	F ₂ flow on. NO-F ₂ mixing in F ₂ manifold F ₂ manifold hot
	E	23.7	1	- 1	19. 2	20.0			i	ı	i	130.7	.5	5.0	283.4	1, 0	7143	14, 2	Replaced by flow with SF4 flow. Orange
	F	.:3, 7	- 1	l,	, a, ,	;s. 6			-			140.2		4.0	282.4	- (2, 8)	7626	14. 2	radiation in cavity.
	.		ļ	j	1		ļ	-								10.01		14.2	Orange radiation in Cavity Some signal on oscilloscope (Au. Ge. Det). Signal diminished
1	c	23.7			30. 2	20. 4	ļ					130, 2	.5	7.7	281.1	- (2.6)	H175		with decrease in NO flow,
1	ł	23.7		- I	- 1	20, 6					- 1	130, 2	.5	1	281.1	- 1	!	14.2	No radiation.
	,	- "			1	1					1			ļ		- (3, 3)	6510	14.0	Orange radiation returned after increasing NO flow
	1							- 1	-	!	ļ	l	Ì	- 1	286, 7	1	1		No change in cavity observations
-	ابر												. 1	- 1	288.7		1		No change in cavity observations
1	- (21.7		- 1	130. 2	20.0		- 1	1		- 1	110. 2		ĺ	281.2	- (2,61	H178	14.2	No radiation.
1	L I	19.7]	161. 1	20, 0					[46, 0	. 3		252.9	- (1.0)	K374	15.6	Decreased H ₂ diluent flow Oral qui radiation in cavity
1	M				68. 1	20.6		-			}	AK. 5	-1	- 1	202, 3	3. 0	92 9 4	19.5	No change in cavity observations.
	N	10.6				J						-		5.0	212.6	4.0	4019	19.4	Returned SF4 flows to original flows. Decreased H_2 and F_3 flows. No radiations.
	6	1 . 6			68. 1	20.6						AN, 5		11, t	219. 1	- (4.0)	4145	18,9	Increased NO flow. No radiation
ĺ	₽ [1		1				[į	3.4	211.5	-	1		Cut off NO flow and then increased NO flow until
	Į			1		1													radiation appeared. Orange radiation appeared at indicated flows (P)
	ن	- 1			175,1	1			1	-	1	0, 0	0,0	1.	229.0				Cut off H ₂ diluent flow, No radiation
1	н	12.9			175.4	20, 6		-			1	0, 0	8,0	1	129.3	(1 10)	4779	18.0	Increased NO flow until radiation appeared. Orange
	İ							1								l	ļ	-	Radiation appeared at indicated flows (R),
4. 6 - 4.	144			}						- 1			į			. 11,7%		i	Initial conditions.

	f 8	1 1	1	1	10, 1	1	y 1	1	1	40.1	1 .4	1	80.8	1 .65	1 9399	1	SF, flow on.
	6		1.			ĺ			77.0	1	l ".	1	146,0	9,0	1380		SF, flow replaced by Ny flow.
		11		\cdot	- 1	16.4	1 1				١.	5.0	157. 4	11,0	1082	1	H _s , NO flows on.
		20, 1	١ .	9. 0	- 1	16. 4	1 1	1	77.0		١.	5.0	177.9	12.0	1114	18.5	F; flow on, grange radiation at H; inlet ports.
	,	20, 1	- }		40. 1	16. 4				40, 1	۰.	5.0	122,3	1,3	7113	26. 0	Replaced N ₂ flow with 5F ₃ flow. Orange radiation in cavity diffuse orange radiation around H ₃ inlet ports.
	G	20. 1			10. 1	16.4				40.1	.6	1.8	117.1	1, 25	7204	27.5	NO flow decreased. No radiation at first - then prange radiation appeared.
	н	20, 1		ŀ	10. 1	16.4				40.1	.6	7.6	126. 9	- (2.3)	(4173)	25.9	NO flow increased. Bright urange radiation around H ₂ inlet ports.
	1	20, 1			10. 1	16.4				40.1	.6	12.6	129.9	- (2.9)	(3387)	25.3	Radiation decreased in intensity.
	J									20.0	1		109,8				Hg diluent decreased. No change in cavity observations,
	ĸ		- 1		- [ĺ		- 1		0,0	0,0	1	89.2			1	Hz diluent flow cut off no change in cavity observations.
	L	20, 1			10, 1	16.4				0.0	0, 0	- (5.	(81.6)	- (1.5)	(4) (3)	40.2	NO flow increased Brigh, diffuse orange radiation downstream of H ₂ inlet ports. Radiation brilliant around H ₂ inlet ports.
	м			•	ه. ه	[4.8	E1.3				Fy diluent flow increased. No change in cavity observations.
- 1	N		- 1			-	1	- }		65.8	. 8	ļ	147.9			1	By diluent flow on. No change in cavity observations.
	P	10.2			-	16.4				0.0	0,0	0.0	16, 5	- (2.0)	(1380)	я9.9	NO flow off. SF4 flow shut off. Hz rich. Blue radiation flashes in cavity.
ļ		"	- 1	Ι,	٠. ۱	10.			-	18.4	.6	5.0	63.0	. 8	5955	12. 4	All flows on and out back from original settings. Orange radiation in cavity.
	Q	10, 2		,	8.0	10,8				18.4	. 6	- (5. ((63.0)	- (1.0)	(4764)	32. 4	NO flow decreased - radiation diminished. Disappeared when NO flow shut off.
- 1				-				- }		0.0	0, 0	İ	14.0				Hg diluent cut off. No radiation observed.
	5	10.2		Ι,	a. a	10.8			- 1	0.0	0,0	4.9	13.9	. 5	6634	46.3	NO flow on Orange radiation visible around H ₂ inlet ports.
	T O	10.2		1.	0. 0 -					0.0				·		1	H ₂ flux decreased. No change in cavity observations.
						(10.4				0.0	0.0	4.9	25, 9	- (2.10)	(979)	7#. H	Signific in flows off. No change in cavity in realism at first, thin blue radiation flashes.
12 Feb	15A		- }		ij]]	.025		}	feitial readings
1	B C		76	-	3. 0					85.0			168. U] -			al gallow on
	D		19			41.6		İ	101.0				23H, H	·			Shadow a photology Nathon Hg, NO flows on.
		1	"	- [59.0			1,0	155, 5				N. G. w. recursed
1	E	35.6			3.0	37. C				P5. 0	. +	4, 0	246.0	16, 4	511	24.0	Fig. 1. w. n. N ₂ flow realized to SF ₃ these. Purple for the er and H ₂ inlet perfectioned to orange as system pump d down.
1	F	35,6		- 1	- 1	37.0				85.0	. 4	1.6	241.4	(36, 2) -	(511)	29, 1	Orange radiation flickering in cavity
	G	35.6		- [- 1	37.0	1	- 1		85.0	. 4	0,0	230.8	(15,6) -	(5)2)	29,6	No fadints of
- {	H	35.6		i	- 1	(37.0)	1			85.0	. +	4.0	215. 4	(36, 11) -	(5: h)	20.3	Lymich Orange radiction
	1	6.5		"	•. •	10.6		-		#5.0	. 6	5. 5	182.7	3.20	2649	7.1	N smarge in cavity observations
	,	1 1	ļ		-							11.3	1 48. 9	'			Increased NO flow and then out at NO flow. No change in coasts observations
	к .	7.0	ļ			10.6				B5. 9	. 6	4. 9	182. 1	7. 9	1713	7.7	Fy cooled with liquid Ny trap in Fy harricade. Orange reduction in caxity and around Hy inlet ports.
- 1	L M	35.0	}	- 1	- 1	37. 0 37. 0			1	35.0	.4	5.0	215, 4	- (15)	(531)	24,4	Bright orange radiation around H ₂ inlet ports.
- 1		"."		•	. "	"."				35.0	.4	10.0	250, 4	- (36)	(526)	28.0	Orange reduction intensity (factuating with Justiniting F ₂ processes)
-	N	35. 0		63	. 0	37. 0				85.0	.4	0.0	240. 4	(34)	(525)	29.1	Badiation disappeared.
20 Feb	15A													.2			NO flow mixed with Π_2 flow. Γ_2 cooled by dry ice tribilities thele no bath adjacent the laser cavity $S\Gamma_4$ dilute times d with the cold Γ_2 in Γ_2 manifold initial conditions.
	В			.,	. 0			1		85,0	.6		170.6	.2	6450	i	SF4 flow on
i	c		53.	1	- }	43. 8		ł	56.0			5.4	158, 8	64.7	146	1	SF ₄ flow replaced by N ₂ flow. H ₂ , NO flows o ₁ ,
1	D			1	ļ								,	74,7	•		Final readings before adding F
	E	10, Z		19	. •	43. 0				85, 0	.6	5. 4	230.0	(30) (decreasing)	(580)	11,0	F_g flow on, N_g flow replaced by SF_g flow. Orange radiation around H_g inlet ports.
į	•				1		-	j	1		-]	2.7	227.3	.		1	Decreased NO flow. No change in cavity observations.
	c	9, 4	}	1	1	43.0		J		85.0	.6	0.0	223. 6	(25) •	(677)	8.4	Diffuse trange radiation in cavity
	H	7.4		ļ	- }	43.0	j		1	85.0	.6	.4	224. 2	(25) -	(678)	8.4	Orange radiation. Signal on oscilloscope, (Au.Ge Detector).
	1	2.4	ĺ	1		43.0				85.0	.6	5. 4	229. 2	(26) -	(667)	R. 2	Orange radiation on Hg inlet ports
	, K	7.4			1	11.1	-			85.0	.6	13.0	236. B	(27. 5) -	(651)	7. 9	Maximum NO flow. No oscilloscope radiation signal orange radiation on H_2 inlet norts
	L	39.7		1	- 1	41.3				85.0	٠.		252.7	13.6	1058	7.8	Same observations as (J).
	=									-3,0		.,	636,7	(12.0)	(1592)	31.4	With NO flow deminishing, a signal which decreased when cavity was spolled was observed. First sign of lazer emission.
21700	16.4												.	. 150			 Initial conditions.

c	11.4	**.*	1 [1	69.6 14,1] 44	, ,	F, flow on
D 4	3, 9 47, 4 41, 4	44.7	1 - 1	1.0	40.5 56,9] :=	,,	ľ
E 40	3, 3 85, 0 39, 9	41,7	1 . 1	1.0	9).9 . (12	t. 0) (1146	ı,	SP, flow replaced by N ₂ flow; H ₂ , NO flows on 15, 3
- .		**. 6	6	0.0 2	11.1	170	,],	1.6 Replaced He flow with RF - tion Co.
G 29.		84.6	.•	0.0	13, 1	1793		1,6 Oscilloscope signal (Au-Ce Det) appeared. Orange radiation present as NO was primped out of rotamet.
H 25,	1 1 2 2 2 3 1	84.6		0.0 22	0. 2 - 18. 0	(1939)	. .	LASER emission.
[20.		84.6		+ /(22	1	1 ""	22	relation ng and Fg flows - no radiation.
J 20.		85.0	'	0.1 21	7.4	2227	10.	on corange radiation oscilloscope signal
K 25. 2	177.7 26.6	85.0	,	0. 1	. 5 - (7. 8)		į	indicating laser emission.
	105. 2 42. 0	79, 2		. 1 272		248)	18.	The continue as (1).
27 Feb 17A							100	5 Increase H _k , F _s , and SF _k flows. Same observations as (I). Photographs of oscilloscope signal taken.
c	40.0	85.0	.6	170.	.125		.	Initial conditions.
۵	41.4	42.2	-	82.		1290		SF, flow on.
E 27.9			.6 >.	1 124.	3 -			SF4 flow replaced by N ₂ flow.
F 38	40.0 42.5			152.	2 } .		1	Hs and NO flows on.
G 29.5	40.0 33.7	42. 2	.6 <0.	1	1,	(1236)	46, 5	F ₂ flow on temporarily, F ₂ tank exhausted. All flows on - blus flashes as system pumped down.
1.11			. 6 <0.1	1 146.	14.0	789	40.4	Orange radicales 1/2 -
H 47, 0	40.0 50.5	42. 2	.6 <0.1	180.4	10.6	1287	29, 9	when cavity spolled.
			Varie	•d			,	manifold.
								Some oscilloscope signal when NO varied. No coherent emission.
								Same observations as (I).
L 47.0	40.0	42. 2		,				F ₂ pressure varied considerably - not intentionally. Same observations as (I).
Mar, ITA								Scan made with Jerrold Ash monochromator of cavity output. No emission lines identified.
6				1	1, 0		1	Pump not pumping correctly. Gold surface cavity mirrors used. Initial conditions.
D	42.0	85.0	.6	169,6	1.30			Conditions before adding diluent flow.
E 40.5	42.0 41.4	12.0	- 0.1	125, 5	12.0	226	-	SF4 flow on.
F 21,9	·	+z. 0 .	0, 1	166.0	17.9	701	18, 8	SF4 flow replaced by N2 flow. N2 and NO flows on.
""	42.0	42.0	6 0.1	138,0	23, 9		10.8	Fr flow on, Ny flow replaced by SF, flow. Orange radiation at Hz inlet parts.
Mar 17A 29, 3	85.0 29.0	85.0				751	31,7	Orange radiation. 3 cm of signal on oscilloscope at 10 mv/cm (Au.Ce Det). Signal decreased to 2 cm when cavity spoiled. LASER emission.
B 27, 8			< 1	229.0	12, 7	1364	25. 3	Initial conditions not noted - 1.5 cm signal at
C 27.8	R5, 0 29, 0	(85, 0) (0, 6		227.5	- !			these flow conditions.
D E 27.8		61.2	. ``	227.5	- (12,0)	(1434)	24.4	Radiation on manifold side.
F 27. 6	85.0 29.0	85.0 .6	1 1	203.6	- 113.01			Increased SF4 diluent flow - same observations as 17A.
G 38.1	85. 0 29. 0	97.4 .7	1 1	240.0	- (12.0)	(1434)	1 ***	Original flow conditions - same observations as 17A
H 38, 1		97.4 .7	1 1	{	14.6	1087	1 23.6	increased SF4 diluent flow. Radiation in exhaust manifold
38.1	85.0 41.8	97.4	0.0 2	263. 0	. 114.5		24.0	increased H ₂ -F ₂ flows to ~40 cc/sec. Radiation at H ₄ inlet ports.
38,1	85.0 41.8	85.0		- 1	- (14. 0)	(1421)	29.0	Reduced NO flow - 2 cm signal on oscilloscope. Detuning cavity did not reduce signal intensity. Not LASER RADIATION.
		85,0 .6	0.0 2	50. 5	- 1	(1353)	1 1	F, diluent flows returned to initial flow conditions.
K 49.7	105, 0		1 1		•	l	l le	leduced SE, diluana ri riv .
I. 49, 7	99. 0 49. 6	97.3 .7	1 1	1		1283		to LASER emission observed. Concepted SF4 diluent flow - no observed change.
M (49,7)	114.0 49.6	114.2 .8	1 1		í	1376	34. 1 R	ediation on H ₂ inlet ports.
	30. 2	85.0 .6	1	[1334	- (adiation in center of ravity.
0 28,9	85, 0 30, 2	85.0			, 16	8045	25. 2 D	euterium flow on. o radiation
P 28,9	85. 0 30, 2	85,0 .6 85.0 .6			{	1271)	25. 2 Re	duced NO flow. Blue-green radiation on H _g
0			0.0		(2. 1)		Wh	sistling noise; visible radiation, center apot radiation systems systems.
s _			0.0			1	Inc	reased SF4 flow - whistling stopped
			<.1				Ora	ange radiation at H ₂ inlet ports added - same observations as 17R.
1 1 1								

										,		,	,				1 1	No change in observations.
	T U	24, 6 22, 1			(85, 0)	41.	,				(85. 0)		۲,۱	233.7	(4, 0)	(441B)	10.4	Flow of H ₈ and F ₉ returned to 40 cc/sec. Bright blue radiation present in manifold. This traversed to H ₁ inlet ports and change in culor to orange
l									ı									Initial conditions - methane fuel.
4 Mar	184							1 1						91.8	3.0		1 1	SF4 diluent flows on.
	9				45. 9						0.0	.,	0.1	20.2			1	SFs flow replaced by Ns flow
	С			•	0.0		20.1				•.•			40, 2				FI flow on Brilliant orange radiation in cavity.
	D	20, 0		٠ ا		-	20. 1		- }		46.0	. 3	[0.1}	132, 4	- (16.0)	(626)	30. Z	SF_4 flow resumed, N_g flow off. Purple radiation in cavity
	E	20.0 17.5			46. 0 68. 0	-	20.1		l				0, 2	152. 1	16. 9	681	23.0	No change in cavity observations.
	F G	18.9			68.0		20. 1	1 1	İ		46.0	. 3	0, 2	153. 5	- (17.0)	(683)	24.6	Bright purple radiation in exhaust manifold
	H	18, 9			32. 5		decre	Leed)			13.0	. 3	0, 2	()	+ {15.0}			Reduced CH ₄ flow and SF ₆ flow. Bright bluish-purple radiation on exhaust manifold side of cavity.
	1	18.9			32. 5						0.0	0.0	0, 2	()	- (13,0)			Green radiation on CH ₆ injet ports, some radiation signal observed on oscilloscope (Au-Ge Det.)
ļ	J	(1)			32, 5						0.0	0.0	a, z	()	- (16.0)			F2 rich. Graphite accumulated on cavity windows.
9 Mar	IBA														2. 5			Initial conditions - window purge supply changed from H ₂ diluent supply to F ₃ diluent supply. Methane fuel.
	В		1	1	46.0						46, 0	. 3		92.3	4, 2	1662		SF4 Diluent flow on.
	c				0.0		59.				0.0	•	<.1				1	SF4 diluent flow replaced by N ₂ flow. CH4. NO flows on.
	a	30.0			46.0		59.	·			46.0	. 3	<0, 1	181.6	(15. 0)	(915)	32.2	F_3 flow on. SF_4 flow on in place of N_2 flow. Bluish white radiation in cavity.
	E	30,0			46.0		59.				46.0	. 3	0.0	181.5	(14.8)	(927)	32. 2	NO flow off. Diffuse blue radiation in cavity.
	F	30. 9	1		46.0		59.	1			46.0	. 3	<,1	183, 2	15.6	888	33.7	No radiation observed.
	G	30,	1		46, 0		59.	,			46.0	. 3	(+)	,	-()			NO flow increased. Blue radiation in cavity. Exhaust manifold hot.
	н	30.			46, C		59.	,			0.0	, 3		137. 2	- (14.0)	(741)	*45.0	Reduced SF_4 flow (CH ₄). Blue radiation on exhaust manifold side of cavity.
	τ	30.	,		(30. 0) decres		59.	9			0.0	(0, 3)	<0.1	k 1	- (13.0)			Reduced SF ₆ flow (F ₈), increased NO flow. Green radiation appeared at CH ₄ inlet ports. Cut off NO flow and radiation remained at ports.
	·	30.	,		46.0		59,	9			0,0	0, 3	۲. ۱	136.9	- (14.0)	(739)	45.1	Increased SF4 diluent flow. Blue radiation appeared in center of cavity. Green radiation disappeared.
	ĸ	30.	,		46.1		59.	,			0.0	6, 3	<.1		-	j		Reduced SF, flow. Green radiation flashed to CH, inlet ports.
	 	l													(.)			Used N ₂ to increase cavity pressure (pump inlet bleed). Green radiation appeared at CH ₄ inlet ports.
	м	30.	•		46.0		49.	9			0.0	0.3	<.1	126.9	- {14, 0	(685)	48.7	Reduced CH, flow. Blue-green radiation flashed in cavity.
	N	30.	9		46.0		49.	•			46, 0	0, 3	<0, 1		- (15.0	,		Reduced SFs flow. Green radiation appeared at inlet ports. NO flow then reduced and increased. Blue radiation spot appeared and moved to center of cavity.
	0	30.	9		(46. 0		49	. 9			0.0	0,3	<0.1	ŀ	- (14,0	,		Reduced SF4 diluent flow (F4) Criss sectation appeared over whole cavity. SF4 diluent off (CH4). Blue radiation appeared at exhaust manifold.
	Р							-							-			Reduced CH4 flow. Radiation was green on CH4 inlet port side of cavity, blue on exhaust manifold side.
	a	30	. 9		(46. (3	(49	. 91			0,0	0.3	<0.1	1	- (14.0)		Reduced SF ₄ diluent flow (F ₂). Blue radiation over whole cavity. Orange radiation appeared at CH ₄ inlet porce when SF ₄ diluent flow cut off (CH ₄).
	R				32.	s	1				1	. 2			-			Increased SF ₆ diluent flow. Cavity pressure increased with N ₂ (pump inlet bleed).
	s	١,,	. 9		75.	,	49	. 9			0.0	. 2	<0, 1	157. 2	38, 6	308	39. 3	Blue radiation across cavity.
	7	1"													-			Cut off N ₂ blend. Blue radiation over whole cavity.
	u	30	1, 3		79.		31	s. a			26. 1	.5	د ۱	171.9	20.0	650	35.3	Blue radiation over cavity. Brighter at exhaust manifold
	v	31	. 3		79.	•	3	5. 9		1	0, 0	0,5	<0, 1	145, 8	- (16,4	(689)	41.6	Reduced SF4 diluent flow (CH4). Radiation became green and moved to CH4 inlet ports.
	w				-		.					-						Reduced SF ₄ diluent flow $\{F_2\}$. Radiation again moved to CH ₄ inlet ports.
	х	,	1.2		79.	.	3	4.4			24. 5	.5		170.	17. 9	719	36.7	Bright blue radiation. Exhaust manifold side. Exhaust manifold hot.
								-	1						-		ļ	CH, flow reduced. Green radiation at CH, inlet ports.
	7.		6.3		46.	•	2	a. 3			0,0	.3	(0.6	73.	(16.0)	(347)	17. 1	No radiation in cavity.
	**	.			.							-	-		-			Reduced CH, flow and F ₂ diluent flow. Increased CH, diluent flow. Unsern radiation appeared at CH, diluent flow. Cut NO flow and radiation remained at ports.
	B:	- !	17.4		46.	. 6		1.0			50.	د. ا		195.	14.7	1006	38.2	Blue radiation on exhaust manifold side of cavity Decreased NO flow. Blue radiation moved to center of cavity.
	ים		17. 4			. 6		11.0			0.	•	(0.6	., 18.	4 (22.0)	(338)	76.0	Cut of SF ₆ flow. Green radiation over entire cavity. Bright green radiation immediately appeared at CH ₆ inlet ports.
	E	Ε	37. 4		16	1.9		61.0			۰.	•	(0.1	6) 117.	3 (19.0)	(467)	63.0	Increased cavity pressure using $N_{\rm z}$ (pump inlet bleed). Green radiation appeared at $CH_{\rm z}$ inlet ports.
	1		ļ					İ	ļ	١	1		1	ł	Į	I	1	

							,			,			I	f 1,3	1	1	NH the . sailed . massame
10 Maz	198]]	- }	1 1	Ì					- 1				3.4	£646		Intuary flows up
}	n	1 1		40.0	l	1	1	} }		46.0			92,4	3.0	2557		MIL live on
)	ť	} }			ĺ		29.5				و .	.,	151.9	15.61	CETAL	,v. e	White costing appeared on principle with a director
1	t)	30, 0		16, 0	{		29, 4		.	14,0	.,		111.	17.47	,,,,,		
11Mar	20A	1 1	- {	1 1	1	- {	{		1	- {	į			9,7		1	Inizial cuiditiona : 14 funt
ĺ	в	{ }	- }	85.0	- 1		-		1	05.0	. 6		170,6	12.7	1614		SF ₄ diluent flues on
1	c	1 1	- }		30.8)		0.1	201.5		ŀ		He flow an
i	D	30.0		1 1	- 1	1	1	1 1	- }	- 1			231.5		[NO flow on
	E	30. 7		85, 0	10. 8				j	85. D	.6	5, 1	131,1	(19.0)<2.0	(424)	16, 1	Fy flow in New Fy tank - urange radiation on Ny Irlef porta - Blue radiation in enhance manifold
	F	30.7		85. 0	33.4					85. 0	- 6	0.1	254, 8	(20,0)	(#48)	26.7	bigned on Operation operating councils with our eignet (Aur.Ge Det.) decreased to 1 cm, which cause aposted a LASEK radiation.
	G	32. 0			35, 5			1	}			₹,1	238, 2				Decreased NO flow - Badistace so couter of causty - Windows logged
	Ħ	30.0		85.0	30,0			} }		85. 0	.6	.1	230.7	-			Original conditions - logged windows decembed output signal to zero
12Mar	20A		- }		.]			1	1			(16.4	1	1	Initial conditions
12 May	B			85.0	30.8	1	1			83.0		.,	200, 9	32,7	465		SF4 dituent flow on Hy and NO flow on
}	c	28.2		1	,,,,,			1 }	}	}		}	229. 1	31.1	457	24.6	F, flow on.
	ם	24.9		85. 0	36.0					85. 0		4.1	231.0	19.3	905	21.6	Orange radiation in cavity, I cm aignal at 5 mis/cm on oacilloscope (Au-Ge Dec.) Signal decreased alightly when cavity spuiled
1	E	35. 5	1	85.0	41.5		})		97.6		0.0	259.6	22.6	867	27.4	Redistion on exhaust manifold side
	F	25.0		85, U					1	85. B		0.0	248.5	20.3	926	20.1	Chipper off. 3 cm (Aa-Ce Det.) apihed radiation emmating from cavity and observed on nacilloscope Visible orange radiation pulsing in tauty and also present Ry indet ports. Small amount of Ny on at pump bleed salet
	C	35.0		85, 0	5z. 8					85. 8		0,0	258.6	(22.0)	(389)	27.1	3 cm signal at 5 me/ cm on oscilluscope. F _d tank empired, terminating experiment.
(J Mar	21 A													13,0			Initial conditions, distortic missus substituted for gold mirrors in cavity (750 mm RC dislectric, dielectric flat). Pump not pumping correctly
1	В	1	Ì	85.0]	- [85.0	.6]	170.6	14.0	921	1	SF ₆ flow on
l	c	i 1			36.2	1 1		1 '	1	1		.1	206.9		1		H ₂ , NO Sowa es.
1	ď	1		}			j	i	: 1	j				32.7	i	1	Final readings before addition of Fg flow
1	E	45. 5	-	85.0	36. 2	} }		ļ		85.0	, 6	(0.1)	252.4	135)	(545)	36.1	Fa flow on Orange radiation on Ha ports.
}	F	"	-	1	10)	1 1	1			1				-	1		Decreased NO flow, increased Hg on SF4 flows.
}	ď	45, 5		99, 2	38,6	1 1			1	99. 2	.7		283, 4	14. 3	1495	52.1	Rediction observed in exhaust manifold
}	н	45.5		99, 2	38,8		1		1	99. 2	. 7	(+)	283, 8)	(14.5)	(1480)	32. 1	Increased NO flow. Radiation moved to cavity center
}	.,	{ ```}	1	(-)	1		1		} }	(-)			[{ -		}	Decreased SFs and Hg flow. Orange radia: on flickered
- 1	j	1 1	}	(+)				1	1	(+)		(1)	}				Increased SF4 on NO flow, Same observations as (11)
	ĸ	50.0			50.0					-							Increased flows to 50 cc/erc on H _F , F _F . Orange radiation was diffuse, radiation center varied with NO flow. 2 cm at 5 mm/cm radiation observed on earliborance (Au-C-Dei). Slight variation in signal when cavity spoiled.
	L	34.6		114.1	29. 1					113. 2		<,1	291.1	15.1	2458	20.0	Decreased flows Observations same as iritial conditions
}	M	32.0		85.0] ,,	٠٦			A5. 0		, 2	253.9	16.4	:074	27. 4	Shut off fig flow, started methane flow. Blue radiation in exhaust manifold.
}	N	32.0		es, a		31	.7			85.0		(+) ×13)	(234)	(16, 4)	(1070)	27. 4	Increased MO flow. Did not displace reduction from exhaust manifold.
	o	32.0	30.0			31	.7	30.0					123.7	(7)	(?)		Stopped SF, dilurnt flow and started Argon Row No radiation observed. Windows began to log
7 Apr	22A													, 025			Initial conditions, F ₂ couled, new H ₂ tank, 250 mm RC dielectric and flat dielectric form optical cavity. NoF trap Laked out prior to this experiment.
	s c			85. 0						85.0				1.3			Initial manometer readings. F_2 manometer pressure :
	Ď			- (41.4	1	1	Ì			.6		1	8, 1			H ₂ flaw on, window purge on
	F					1	1		}	1		.1	1	5.4	}	1	NO flow on Final conditions before addition of Fg
	F	1						1	[]	}			1		{	1	Fg leak - all flows except H2 flow off
	J	1		1						}	}	1	1	-	1	1	System pumped down
	н				1					1	1	}		. 015		{	Initial conditions before restart.
	,			85.	a					#5. O			}	1. 7	1		SFe diluent flow on
	,	1	1	1	41.4	11	1				. 6	1	1	11.4	1	l	He. NO and window purge flows on
	k K	16.0		85.	0 { 41	.	1	{		85. a	0.6	,1	248. 1	1.9	9873	29.6	Fy flow on, dim and diffuse crange radiation in cavity
	L	19.7	1 1	R5.	9 44.	a				85,0	0.6	1.	254, 4	2.1	9160	31.2	Diffuse crange radiation

NOT REPRODUCIBLE

					_												
	"	19.	11	"	۰۹ ،	٠.٥			1 1"	•] •	P. Ł		192. 6	1.7	851.0	1 4.	flecrossed SF ₆ diluses flus on H ₆ , no change in radiation
	, ×	"	1 1	"	9 41	۱. ۱			"		Ď, &	1 .1	192.5	.	}		Lucrosod MT flow Bright crange radiation in Lavity on mandeld side.
	°	"	ł ł	34.		-			"	• •	0.4	6.1	290, 3	3, 1	4175	17.1	Decreased H ₀ and H ₀ flow v crange radiation on H ₀ inlet port cide.
		19.1	1 1	"`	1.				**.	• -	2. á	0.8	219. 1	1.1	1746	39. 2	Fy dilused flow as criginal flow condition. Orange radiation in center of cavity
	٩	1**.	1 1	•5.		i		ļ	11.	۰	.4	0, 2	270.1	1.1	7198	37.4	He diluent flow at ariginal flow condition. Orange rediction moved to exhaust manifold side of cavity.
		44. 1		45.		1		-	• • •	• •		(-10.1	270.2				Decreased NO flow - orange radiotion moved into exhaust manifold
	3	49.7		100.	1				100.		. 6	0.1	100. 2				Increased SF flow No change in cavity observations
	7	49,5	1 1	114.	1	1	1 1		1113.	۰- ۱	. t	f.1	327. 1	11.9	2114	27,2	Some orange radiation in cavity and exhaust manifold.
		25, 5		85.					65.	١	. 6	5.3	223,0	13.7	1231	22.4	Reduced NO flow, \$F4 at original flows. Diffuse orange radiation on H4 salet port side
	٧	25,5		95.	0) 26.	1	1 1		85.	0 0	. 6	< 4.1	223, 0		}	- 1	No change
		25. 5		(-)	26.	1			(-)		•	40,1		1			Reduced SF ₆ flow. Orange radiation moved to H ₂ inlet ports.
	. X	25.5		(-)	26.	1			1-3	- 1		ə, a					No change.
13 Apr	23A			(1 1		(-)			6.0		1			No change.
17.4														0,50			CC; and NO; flow combined, gold mirrors, 21,8" FL: Gar torm optical cavity, 2 mm coupling hole, KCl aindows - initial conditions.
1	Б С				20.	1	1 1	- 1 - 1			1	0, 0, 80, 54	100.6	5,0	2536		He flow on.
ĺ	۵		ļ	1	1		1 1		- [ĺ		1	١.	1	1	COg flow on and then cut off
- 1			1	50. 8		1	1 1	1 1	50.1	6.	۰ ا	. 1, 0.0	•	3,1	-	j	NO and SF4 diluent flows on
1	£	21.4		50, 8	20,	1		1 1	50, 1	6.	•	0.1, 0.0	Ì	2. 1			Uncooled F: flow on - greenish-prange diffuse radiation in cavity
}	F G	20, 7										0.0, 60.		٠			NO flow stopped when CO ₂ flow started (insufficient NO pressure).
1	н	20.7		50. 8 30, 8	20, 1	1			50, 1	6.1	1	. 2, 9,0°	1	1, 1 4, 1	31.07	27. 2	NCI flow on. Orange radiation at Hg inlet ports.
1	1	20, 7		50. 8	29.1			1	50.1	6.1	j	0. 2, 1-40			4212	17.6	CO, flow on - no radiation.
İ	3	20.7		50, 4	20. :				50.1	6.0		e 1 ,{1,1*					Reduced, three that off COs flow. Orange radiation appeared at H. inlet peris.
- 1	ĸ	0.0	1	50.8		21.2			50.1	١.,	. }				1	Į.	Varied CO ₂ and NO flowe No LASER radiation.
-	Ł	21. 2		50. B		21.2			50.1	6.1	- 1	. 6, (o. a)·	149.3	5. 4 3. 9	1802 3763	28,4	Switch to deuterium, Fg naccoled Fr tion on - an
1	M	21, 2	- } -	50. B		21.2			50.1	6.0		.6, 41.14	141.0	4, 6	3140	1	1
- 1	N	21. Z	- 1	50, 6		21.2		1 1	50, 1	1		4, 0, 20	149,7	4.6	1	22.2	CO: flow on - no radiation observed.
}	0	21. 2		50. 6		21.2		1 1	50.1		- 1	4, (-)*		-	2461	28, 5	Blue radiation with CO, flow off,
	P	21. 2		30. 8		21. 2			50.1	6.0	- [н -, -р					CO ₂ flow on Some blue radiation. Increased CO ₂ flow and then varied CO ₂ and NO
i	Q	0.0	1	50. B	20. I	ĺĺ	1		50.1	١	l.				1	1	No LASER reduction observed.
1	*	18.0		50. B	22.5			1 1	50.1	6.0	- }	- 1	128,0	3.7	2616		F ₂ cooled. Switch to H ₆ initial conditions,
	5	14.0		50. 8	22.5				50.1		-		- 1		1013	24.3	Fy flow on. Orange radiation on Hg inlet port side of cavity.
]	т	14.0	- 1 1	50, 8	22. 5		- 1		1	6.0		0. 34.8	18Z. Z	4.7	5421	19.8	CO2 flow on. Orange radiation over whole cavity.
	Ü								50.1	6.0), 34.8					Decreased NO flow - orange radiation centered in cavity. Slowed pumping speed with No. Radiation intensity
-	v	30.7		50, 8	41.4				50. 1	6,0		34. 6*	213.8	2.9	5574	28.7	increased. Shut off Ng.
	*	22.5		50. 8	į	30, 1			50.1	6.0		0.0-	59.5	2, 4	5025		Increased H ₂ and T ₂ flow. Varied CO ₂ and NO flows No LASER radiation observed
}	×	22. 5		50. 8		30, 2			50.1	6.0	l.	-)(1,-)-	- 1] ""	28, ≥	Switch to deuterium - initial conditions.
	*	0.0		50. 8	40. C				50. 1	6,0		-, -•	- 1				Added CO ₂ . Tried variety of CO ₂ and NO flows Blue radiation observed
	z	42.4		50, B	61.4				50. 1	6.0			1	•			Switch to H ₂ . Initial conditions F ₂ flow on
- 1	^^	42.4		50. A	41.4				50, 1	6, 0	. 2.	. 26. 00 2	16. 9	4,4	5727	36, 2	Reduced NO flow. Some arange radiation on
1	ਰਵ	4Z. 4		50. 1	41.4				0,0	6, 0	0. 2	2, 26. 0	66. R	4, 3	2993	49,6	Shut off SF2 diluent on He. No change in cavity
	cc	42, 4		0.0	41.4				0,0	6.0	0. 2	t, 26.0 1	16.0	3, 4	Z580	71.4	Shul off SF, diluent on F. Blee radiation and M.
	DD	42.4		0.0	*1. *				0.0	6. 0		0.0					NO flow off Orence reduction in cavity.
1	ł	i	1 1	ı	l	1	1	1 1			1		1	į			No LASER radiation observed

either increased or decreased but could not be estimated. A tape recorder was used to record pressures, flows, etc., during an experiment, and some flow data were sometimes lost by this process.

The experiments in Table I are listed chronologically. For the purpose of discussion, groups of experiments in which certain common features pertain, will be discussed individually.

a. Initial Experiments

The first experiments after reactivation of the laser system following a period of inactivity between renewal of contracts was for system check-out and for familiarization of Captain William Glass, of the Physical Sciences Laboratory who assisted with later experiments, with equipment, procedures. etc. Conditions approximating those reported in Ref. 3 were utilized for check-out of the system, and are listed in the Table. Results obtained were analogous to those reported previously (Experiments 11-12 January and 27-January 29); ie. no laser radiation was observed emanating from the cavity; only visible orange radiation was observed, the location of which could be varied by variation in flow.

Conclusions drawn from the previous series of experiments (Ref. 3) were that failure to observe laser radiation might result from the lack of a sufficient number of emitting species in the cavity mode volume.

When attempts were made to increase cavity pressure and, thereby, the concentration of emitters, excessive heating of the manifold resulted in shut-down of the system. This type of experimentation was then deferred until a means of cooling the manifold was devised.

b. Experiments with Premixed F2-NO

From the previous experiments it was concluded that an insufficient number of emitters were being generated in the laser cavity mode volume. One possible means of increasing this number is the premixing of the F_2 and NO, thereby allowing a greater concentration of F atoms, via Reaction (1) to build up before injection of H_2 into the flow. This approach has also been used by T. A. Cool and R. R. Stephens in this CW laser system (5) and worked satisfactorily in their glass apparatus.

In the experiments run in the laminar diffusive-mixing laser system (Monel^{® 1} construction), (12-13 Feb)-(15-18 Feb) reaction occurred at the hydrogen inlet pots. It was assumed that the Monel tubes offered a catalytic surface and hence a stabilizing effect on the reaction zone. This reaction zone, as evidenced by orange radiation, could not be moved downstream except under extreme conditions, i.e., no NO flow or high-diluent flow, etc., and with little chance of observing laser radiation existing.

Since it had been concluded previously that the orange radiation (3) was characteristic of deactivated HF, with the result that attainment is highly improbable when it is observed, further experiments in this configuration were discontinued.

c. Experiments with Pre-cooled F₂

Since it had been observed in previous experiments that the orange radiation could be moved downstream, but not readily so in the case of premixed NO + F_2 , it was then concluded that it might be best to ensure that the F_2 passed the H_2 inlet ports while in the molecular state and rely on the reaction (1) to generate the first F atoms. Hopefully, with higher concentrations, this reaction plus the two HF reactions

$$F + H_2 \longrightarrow HF + H \tag{2}$$

$$H + F_2 \longrightarrow HF + F$$
 (3)

could supply sufficient F and activated HF in the cavity-mode volume for laser radiation to be observed. Additionally, catalysis effects should be minimized as the gas flow passes around the $\rm H_2$ inlet ports.

The flow system was plumbed, as previously described, to accommodate cooling of the F_2 while allowing the diluent to mix with the F_2 in the F_2 manifold of the laser cavity. The NO and H_2 mixing configurations were returned to the normal configuration, i.e., the configuration used before the previous NO- F_2 premix experiments.

CW coherent radiation was first observed under conditions of 15L - 20 Feb. The radiation was observed for periods of 1/2 min. under conditions in which NO flow was rapidly diminishing. The rotameter size used prevented stabilizing conditions satisfactorily.

¹ Trademark of The International Nickel Co., Inc., Huntington, W. Va.

Even in later experiments with the smallest diameter rotameter and with smallest flow that could be maintained, the minute amount of NO required still remained a problem.

Attempts were made to maximize the amount of radiation, but insufficient intensity was obtained to allow characterizing of the radiation via the monochromator-detector system. Coherence was verified by detuning the cavity (blocking one of the cavity mirrors).

Under the best operating conditions, 16-23 Feb. 1970, a CW signal could be maintained as long as the F_2 and NO flow could be maintained constant (2-5 min.). Estimation of power output was made by comparison of signal of He-Ne laser and approximated μ watt for the optical configuration detailed previously with the exception of the 500-mm focal length curved mirror in place of that indicated in the schematic (Fig. 2). The beam splitter was set 5° off the Brewster angle, which for sapphire reflects 0.61% per surface.

Attempts to improve signal output by use of gold surface mirrors 17-4 March were only slightly successful. A greater amount of incoherent radiation was observed along with coherent radiation. Estimated power output was 5μ watts. Again, neither the coherent nor non-coherent radiation was of sufficient intensity to be measured via the monochromator-detector system.

d. Experiments with Other Fuels

Since experimentation time was limited and it was agreed that the original objective had been met, i.e., demonstration of CW coherent emission using only commercial bottled gases and with no external energy sources required, a decision was made to investigate other fuels in the laminar diffusive-mixing laser system. These experiments comprised experiments 17-5 March through 19-10 March.

No evidence of coherent radiation was observed using D_2 , CH_4 or NH_3 . Blue radiation was observed in the case of D_2 in contrast to the orange with H_2 . Blue, green, and violet radiation was observed with CH_4 dependent on flow conditions. Deposits of NH_4F and carbon on the cavity windows limited flow conditions that could be attempted with these fuels. Pressure build-up in the fuel manifold system, (the system as designed for H_2 fuel requires 0.0135-in.-diameter holes in the inlet-port tubes), further restricted the operating range.

e. Concluding Experiments

Since fuels other than H_2 appeared less than promising, the remaining experimentation time was utilized in attempts to characterize the observed coherent radiation of HF and to observe 10.6-micron CO_2 radiation via HF and DF energy transfer to CO_2 . The former comprised experiments 20-11 March to 22-7 April in which coherent radiation was observed but little increase in power output was realized even though large flow throughputs were used. Apparently the system is limited by pumping capacity and flow capacity when flows of 40 cc/sec STP or greater for H_2 and F_2 are attempted. While both reaction products and diluent are cryogenically pumped, this capacity must be exceeded in these flow regimes.

Experiments 23-13 April was an attempt to utilize the energy transfer from excited HF or DF to CO₂. This had been accomplished by Cool and Stephens in their system (5). For experiment 23, the CO₂ was premixed with NO and introduced into the fuel line leading to the laser cavity. The optical system was changed to a 2-mm-hole-coupled hemispherical cavity (gold-surfaced flat and 20.5 in. focal length gold-surfaced concave mirror). KCl windows replaced the sapphire windows of the cavity.

Both H₂ and D fuels were utilized; however, no evidence of coherent radiation was observed. Visible orange radiation was observed. This was the concluding experiment; further experimental work on the system, as it has been described, has been terminated.

Section III. DISCUSSION

Upon conclusion of the final experiment in the laminar diffusion-mixing laser system, it appears that realization of high power output from such a system is highly unlikely. The inability to obtain desired concentration levels in the cavity-mode volume is, more than likely, the major deterrent in this system. The device, when coherent radiation was observed, was probably operating near laser threshold. What effects greater pumping rates and fast throughputs might have cannot presently be evaluated.

Doubts currently exist for the suitability of SF_6 as the diluent. It was required in this system because of limited vacuum pumping capacity.

It is significant that coherent CW laser radiation was observed in this system. Output power was miniscule compared with some other types of HF laser systems (6). However, it was in keeping with observations of Cool and Stephens (7), whose system is based on the concept of laminar diffusive mixing even though the axis of observation was different in the two cases; Cool's was axial to the flow while that of this facility's system was transverse to the gas flow.

No further work is contemplated by this facility as all work in this research facility is being terminated.

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